California Environmental Protection Agency

Air Resources Board

DRAFT FOR BOARD REVIEW

Report to the California Legislature

INDOOR AIR POLLUTION IN CALIFORNIA

A report submitted by:

California Air Resources Board

Pursuant to Health and Safety Code § 39930
(Assembly Bill 1173, Keeley, 2002)

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Arnold Schwarzenegger
Governor

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EXECUTIVE SUMMARY

I. INTRODUCTION

The California Air Resources Board (ARB) staff prepared this report to the Legislature on indoor air quality in response to requirements of Assembly Bill 1173 (Keeley, 2002; California Health and Safety Code [HSC] Section [§] 39930). This report summarizes the best scientific information available on indoor air pollution, including: information on common indoor pollutants and their sources; the potential health impacts of indoor pollutants, and associated costs; existing regulations and practices; options for mitigation in schools, homes, and non-industrial workplaces; and other information specified in the legislation. Stakeholder input was obtained from relevant state agencies, industries, interest groups, and the public. The report was also reviewed by a panel of University of California scientists with expertise in various aspects of indoor air quality and air pollution exposure.

Indoor Air Pollution Poses Substantial Health Risks

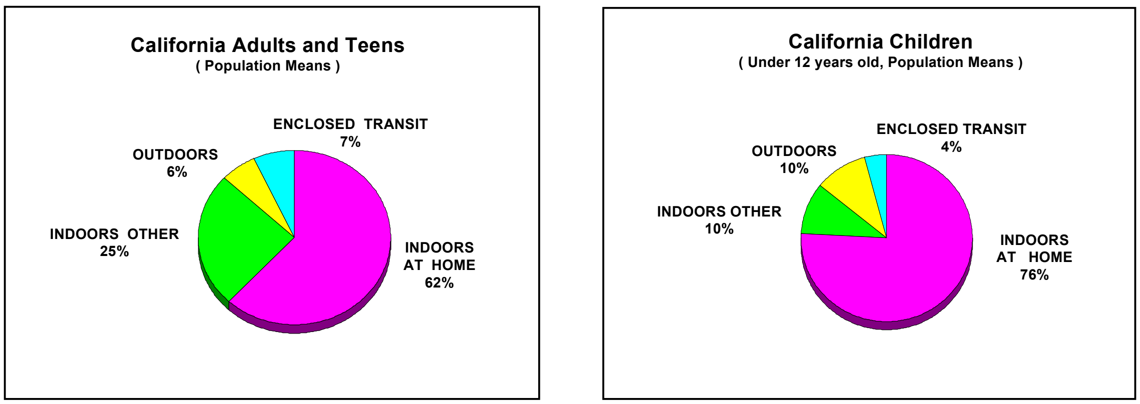
Available scientific information indicates that indoor air pollution poses substantial health risks in many indoor environments. In comparative risk projects that ranked environmental health problems in order of the risk they pose to health and the environment, both the California and U.S. Environmental Protection Agencies ranked indoor pollutants and sources in the high-risk categories. Outdoor pollution emissions from motor vehicles and stationary (industrial) sources were also ranked high. Indoor pollution ranked high relative to other environmental problems because there are numerous sources of pollutants indoors, indoor air concentrations of some pollutants often occur at levels that create significant health risks, and people spend most of their time indoors. While regulation of outdoor sources such as motor vehicles and industrial facilities is very extensive and has notably reduced pollutant levels in California, indoor pollution sources have not been addressed in a comprehensive manner. If such an effort were established, significant gains could be achieved in public health protection from reductions in indoor source emissions and from other measures that might be taken to reduce indoor concentrations and exposures.

Why Indoor Sources Have Such a Significant Impact

The total quantity of air pollutants emitted indoors is less than that emitted by outdoor sources. However, once emitted, indoor air pollutants are diluted much more slowly, due to the partial trapping effect of the building shell. Additionally, indoor emissions occur in closer proximity to people: Californians, like others from industrialized nations, spend most of their time indoors. As shown in Figure ES-1, California adults spend an average of 87 percent of their time indoors, and children under 12 years of age spend about 86 percent of their time indoors. Most of the time spent indoors is spent in the home. However, working adults spend about 25 percent of their time at other indoor locations such as office buildings, stores, and restaurants, primarily for work, and children spend about 21 percent of their time in school on a school day. Senior individuals spend a great deal of time in their homes. Because of these time budgets, the trapping effect of buildings, and people's proximity to indoor sources of emissions, there is a much higher likelihood that people will be exposed to indoor pollutants than outdoor pollutants. Investigators have calculated that pollutants emitted indoors have a 1000-fold greater chance of being inhaled than do those emitted outdoors (Smith, 1988; Bennet *et al.*, 2002; Lai *et al.*, 2000).

Homes and schools are thus critical exposure microenvironments, especially for children and seniors. These groups are more sensitive to the adverse effects of some pollutants, and spend most of their time indoors. The passenger compartments of cars and buses also are key exposure environments: studies have shown very high levels of vehicle exhaust pollutants inside cars and school buses as they travel along California roadways. However, these environments differ significantly from building environments and are more closely associated with outdoor pollution, and are not considered further in this report.

Figure ES-1: Where Californians Spend Time
(Jenkins *et al.*, 1992a; Phillips *et al.*, 1991)



Children Are Especially Vulnerable to Poor Indoor Air Quality

Children may be especially vulnerable to poor indoor air quality due to several factors. Children's physiology and developing bodies make them more susceptible to chemicals that affect development and lung function. Their immune systems are not fully developed, and their growing organs are more easily harmed. Additionally, infants and children inhale more air relative to their size than do adults at a given level of activity, so that they inhale a larger dose of pollutants than do adults in the same environment. Children also tend to be more active than adults. These factors, combined with elevated indoor concentrations of pollutants, can lead to higher exposure and risk for children than adults.

II. HEALTH EFFECTS OF INDOOR POLLUTANTS

Indoor air pollution can cause a variety of impacts on human health, from irritant effects to respiratory disease, cancer, and premature death. Indoor air pollutants can be elevated to levels that may result in adverse health effects. The major indoor pollutants that can have a substantial impact on Californians' health are listed in Table ES-1, along with their sources and associated health impacts. The health impacts of greatest significance include asthma, cancer, premature death, respiratory disease and symptoms, and irritant effects.

Modern society includes many trade-offs, often characterized through risk/benefit analyses. Transportation, building materials, appliances, consumer products, plastics, and pesticides

Table ES-1. Sources and Potential Health Effects of Major Indoor Air Pollutants

POLLUTANT	MAJOR INDOOR SOURCES	POTENTIAL HEALTH EFFECTS ASSOCIATED WITH ONE OR MORE OF THE POLLUTANTS LISTED*
Asbestos	Building materials in older homes released during renovation, naturally occurring in some soils	Lung cancer, asbestosis, mesothelioma
Biological Agents (bacteria, fungi, viruses, house dust mites, animal dander; cockroaches, microbial VOCs)	House and floor dust; pets; bedding; poorly maintained air- conditioners, humidifiers, dehumidifiers; moist structures or furnishings; insect infestation; building occupants	Allergic reactions; asthma; eye, nose, and throat irritation; humidifier fever, influenza, and other infectious diseases
Carbon Monoxide	Unvented or malfunctioning gas and propane appliances, wood stoves, fireplaces, tobacco smoke, motor vehicles in attached garages	Headache; nausea; angina; impaired vision and mental functioning; fatal at high concentrations
Endocrine Disruptors (phthalates; DDT, chlordane, heptachlor, *o*-phenylphenol; PBDEs)	Plastics; pesticides; flame retardants	Mimic or block natural effects of hormones (estrogen and others); developmental abnormalities
Environmental Tobacco Smoke (ETS)	Cigarettes, cigars, and pipes	Respiratory irritation, bronchitis and pneumonia in children; asthma in preschool children; lung cancer; heart disease; aggravated asthma, decreased lung function
Formaldehyde, Other Aldehydes	Composite wood products such as plywood and particleboard; furnishings; wallpaper; durable press fabrics; paints; combustion appliances; tobacco smoke	Cancer; eye, nose, and throat irritation; headache; allergic reactions; aggravated asthma, decreased lung function
Lead	Lead paint chips, contaminated soil	Learning impairment
Nitrogen Dioxide	Unvented or malfunctioning gas appliances, other combustion appliances	Aggravated asthma, decreased lung function; eye, nose, and throat irritation; increased respiratory disease in children
Organic Chemicals (benzene, chloroform, para-dichlorobenzene, methylene chloride, perchloroethylene, phthalates, styrene, others)	Solvents; glues; cleaning agents; pesticides; building materials; paints; treated water; moth repellents; dry-cleaned clothing; air fresheners;	Cancer; eye, nose, throat irritation; aggravated asthma, decreased lung function; headaches; at high levels: loss of coordination; damage to liver, kidney and brain
Ozone	Infiltration of outdoor air, ozone generating air "purifiers", office machines	Lung inflammation, aggravated asthma, cough, wheeze, chest pain
Particulate Matter	Cigarettes, wood stoves, fireplaces, cooking, candles, aerosol sprays, house dust	Increased mortality and hospital admissions; lung cancer; eye, nose, throat irritation; increased susceptibility to sinus and respiratory infections; bronchitis; aggravated asthma, decreased lung function
Polycyclic Aromatic Hydrocarbons (PAH)	Cigarette smoke, cooking, woodburning	Cancer; gene mutation
Radon	Uranium-bearing soil under buildings, ground-water, construction materials	Lung cancer (especially in smokers)

* Please note that when multiple pollutants are listed in a group, each pollutant may not cause all of the health effects listed in the third column.

impart obvious benefits to society. However, it is noted that the use of many beneficial or desirable products at times have a down side – the emission of a variety of chemicals that can have an adverse impact on human health. The impact on health depends on the toxicological properties of the chemical and the exposure and absorbed dose an individual may receive.

Asthma

Asthma is a chronic inflammatory lung disease that results in constriction of the airways. Its prevalence has increased dramatically both in California and throughout the country over the past few decades. According to 2001 data, 11.9 percent of Californians, or 3.9 million people, have asthma (CHIS, 2003). Children have been especially affected; in California, asthma prevalence is greatest among 12 to 17 year olds.

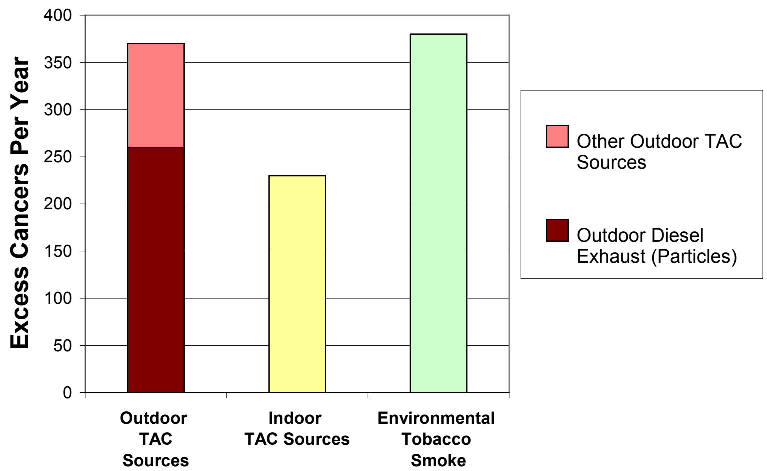
Indoor air pollutants exacerbate asthma symptoms, resulting in breathing difficulties. A recent Institute of Medicine (National Academy) report, *Clearing the Air: Asthma and Indoor Exposures* (IOM, 2000), identified new associations between indoor air pollutants and asthma, in addition to the traditional indoor asthma triggers such as cat and dog dander, house dust mites, and environmental tobacco smoke (ETS). The scientists found sufficient evidence of an association between exacerbation of asthma and exposure to high levels of nitrogen dioxide (NO_2) and other nitrogen species (NO_X), and mold. They found limited or suggestive evidence of an association of asthma exacerbation with exposure to formaldehyde and fragrances. A more recent review of indoor pollution studies further identified several links between asthma symptoms and specific volatile organic chemicals (VOCs), especially formaldehyde (Delfino, 2002). Studies of workplace asthma have further demonstrated an association between asthma symptoms and VOCs, primarily from cleaning products (Rosenman *et al.*, 2003). Several studies also have found an association of increased outdoor ozone levels with exacerbation of asthma, and one study recently linked ozone with the development of asthma in children who are active outdoors. Similar effects would be expected with exposure to ozone indoors.

Cancer

A substantial number of common indoor pollutants have been classified as carcinogens. Examples include formaldehyde, benzo(a)pyrene and other polycyclic aromatic hydrocarbons (PAHs), tobacco smoke, benzene, chlorinated solvents such as tetrachloroethylene, and radon gas. Several studies have measured indoor concentrations of carcinogenic chemicals in California homes. Results have shown that carcinogens, especially formaldehyde, are routinely found in most homes, often at higher concentrations than concurrent outdoor levels, due to the presence of indoor sources. These concentrations result in extended indoor exposures, which translate to a significant increase in cancer risk attributable to indoor pollutants, primarily those emitted from building materials and consumer products. As shown in Figure ES-2, ARB staff estimate that about 230 excess cancer cases may occur annually in California due to exposures from the limited number of indoor toxic air contaminants that can be quantified from residential and consumer sources. This estimate approaches the estimated cancer burden from outdoor diesel exhaust particles, which is responsible for much of the excess cancer burden associated with breathing ambient air in California. This indoor cancer estimate also equals about two-thirds of the total burden from excess cancer resulting from outdoor air pollutant emissions.

Exposure to environmental tobacco smoke (ETS) makes a significant contribution to the cancer burden from air pollution as well. OEHHA has recently estimated about 400 excess cancers from ETS for the year 2004, which translates to about 380 excess cases for the year 2000, shown in Figure ES-2 for comparability (fully discussed in Sections 2.1.2, 2.3.3, and 3.1.3). Those ETS risk levels are similar to the total outdoor burden. Despite workplace restrictions and other positive trends, the risk from ETS will remain significant, because some individuals, especially children in households with smokers, are still exposed to substantial levels of ETS.

Figure ES-2:
Estimated Potential Cancer Burden from Air Toxics in California by Source



Radon, a radioactive gas, enters indoor environments from uranium-containing soil and rock under and near buildings, and from some domestic water obtained from groundwater and wells, and decays into radioactive radionuclides often called radon daughters. Only an estimated 0.8 percent of California residences have annual radon levels above 4 picoCuries per liter (pCi/l), U.S. EPA's recommended mitigation level. However, due to its potency and synergism with tobacco smoke, a preliminary estimate extrapolated from national data shows that radon may contribute to 1500 excess lung cancer deaths per year in California. However, the risk from radon cannot be fully differentiated from that of exposure to tobacco smoke (NRC, 1999a), and reducing exposure to tobacco smoke is the most effective measure to reduce the risk of lung cancer (NRC, 1999a; Mendez *et al.*, 1998). Additionally, this may be an overestimate, because exposure to tobacco smoke is notably lower in California than in the rest of the nation, and recent measurements indicate somewhat lower radon levels in the Sierra Nevada foothills than previously measured, indicating that statewide levels may be lower as well. In light of these factors, the actual radon risk in California is uncertain. Because elevated radon is found in just a few areas in California, and can vary from building to building, radon mitigation is not recommended in existing buildings until adequate testing has been conducted in each building, and preventive measures are recommended in new buildings only in areas where radon soil levels are elevated.

Irritant Effects

Many indoor pollutants cause eye, nose, throat, and respiratory tract irritation. Aldehydes, as well as some other VOCs and oxidants, are known mucous membrane irritants. Formaldehyde is the most commonly identified irritant. Acute effects of irritant chemicals can include respiratory and eye irritation, headache, difficulty breathing, and nausea. Some of these effects, particularly respiratory symptoms and eye, nose, and throat irritation can also be experienced with chronic exposure. Terpenes, such as pinene and limonene, frequently used in cleaning products for their favorable odor characteristics and solvent properties, react with indoor oxidants to produce formaldehyde and ultrafine PM. Further research is needed to understand the extent and duration of exposure to terpene reaction products, and the potential health effects of those exposures.

Irritant chemicals and other factors are suspected of causing or contributing to episodes of Sick Building Syndrome (SBS), in which a large number of building occupants experience irritant and neurological effects while they are in a building. The specific causes of SBS have not yet been firmly identified; however, SBS episodes can affect a high number of workers, have been well documented, and have resulted in high costs to some businesses due to reduced productivity and, in some cases, legal settlements. The most common symptoms include eye irritation, congested nose, headache, fatigue, difficulty concentrating, and skin rash.

Premature Death and Increased Disease

Several pollutants for which ambient air quality standards have been established occur at elevated levels indoors due to emissions from indoor sources. In other cases, indoor sources increase the high levels of exposure that occur when high levels of polluted ambient air enters the indoor space. Ambient particulate matter (PM) has been associated with premature death and serious respiratory and cardiovascular effects in numerous studies. Carbon monoxide (CO) can cause death with high exposures of relatively short duration, and lower levels can cause flu-like symptoms and other health effects. Nitrogen dioxide (NO_2) can harm the lungs and other mucous membranes, cause respiratory disease, and exacerbate asthma. Ozone can have similar effects at elevated levels; however, indoor levels are typically lower than outdoor levels. Indoor sources of these pollutants sometimes cause indoor concentrations that exceed health-based ambient air quality standards established for outdoor air.

Particulate matter

Particulate matter (PM) is a complex mixture of very small particles and other non-gaseous materials suspended in the air. Indoor particle sources include combustion devices such as woodstoves and fireplaces, and activities such as smoking, cooking, candle burning, and vacuuming, all of which can produce PM with harmful components similar to those found in outdoor air. Indoor particles also include fibrous materials, pollen, mold spores and fragments, and tracked-in soil particles. Pollens and mold can trigger allergies and asthma. Tracked-in particles and some particles from combustion sources become trapped in carpets and have been shown to include a mix of toxic components such as polycyclic aromatic hydrocarbons (PAHs) and lead.

A large number of major epidemiologic studies have consistently shown a strong association between outdoor (ambient) PM concentrations and increased mortality from cardiovascular and respiratory disease. They also have shown increased morbidity effects with increased PM levels, including increased hospitalizations and emergency room visits due to respiratory problems such as asthma, chronic obstructive pulmonary disease (COPD), chronic bronchitis, and pneumonia; increased respiratory symptoms such as cough and wheeze; decreased lung function and reduced lung function growth in children; and increased cardiovascular disease such as congestive heart failure, stroke, and ischemic heart disease.

The studies documenting these effects measured outdoor particles, which are composed of a mix of particles from combustion sources, soil, and particles formed through chemical reactions in the atmosphere. Because a substantial portion of PM from indoor sources is similar to outdoor PM components, indoor PM emissions are highly likely to be significant contributors to the adverse impacts seen in the epidemiology studies, and they may also contribute to those effects beyond the levels quantified in the epidemiology studies.

Reducing outdoor PM concentrations to the level of the current California ambient air quality standard for PM would result in significant reductions in adverse health effects, including approximately 6,500 deaths and 17,000 serious, non-fatal illnesses each year in California (ARB/OEHHA, 2002). Although current studies have not directly addressed the potential impacts of indoor PM on health, if consistent with outdoor PM, the impacts of PM of indoor origin are likely to have very large impacts on public health, potentially resulting in thousands of additional cases of serious illness and disease each year.

Carbon monoxide

Carbon monoxide (CO) is a colorless, odorless gas that causes flu-like symptoms (headache, nausea, lethargy) and inability to concentrate, at lower exposure levels over periods of time. At very high levels, CO can cause unconsciousness and even death. CO is a product of incomplete combustion, emitted from sources such as vehicle exhaust, gas and propane stoves and furnaces, woodstoves, kerosene heaters, and cigarettes.

Very high levels of CO occur relatively infrequently indoors. However, a California study of death certificates showed that about 30 – 40 deaths occurred in California each year, on average, due to unintentional CO poisoning (Girman *et al.*, 1998; Liu *et al.*, 1993a, 2000). About two-thirds of those deaths were attributable to indoor sources. The indoor sources most implicated in past CO poisonings were combustion appliances, such as malfunctioning or poorly tuned gas or propane furnaces and stoves, and the improper use of charcoal grills and hibachis indoors (contrary to warnings). Motor vehicles, such as those unwisely left running in a garage, also have taken a substantial toll. The relevant literature also indicates that other CO health effects occur: hundreds of emergency room visits and thousands of misdiagnosed flu-like illnesses due to non-fatal CO poisoning are estimated to occur each year.

Nitrogen dioxide and associated acids

Nitrogen dioxide (NO_2) is a red to dark brown gas with a pungent acrid odor. Adverse health effects attributable to NO_2 include exacerbation of asthma (especially in children), respiratory symptoms and infection, lung damage, and lung disease after long periods of exposure. Indoor sources of NO_2 include gas and propane appliances, wood burning stoves and fireplaces, kerosene heaters, charcoal grills, and motor vehicles. Indoor levels can be especially elevated from the use of older wall furnaces, when their exhaust is not vented to the outdoors, and from gas stoves, because people often do not use the exhaust hoods above them, or the exhaust is not vented to the outdoors. Several nitrogen compounds related to NO_2 also are found in indoor environments, including nitrous acid (HONO) and nitric oxide (NO). Nitrogen dioxide is the only nitrogen oxide regulated as a pollutant in outdoor air.

Ozone

Ozone is a serious respiratory irritant and a main component of smog. Outdoor ozone is the primary source of indoor concentrations of ozone in most indoor environments, but ozone also is directly emitted indoors from some types of "air cleaners", and from poorly maintained laser printers and other types of office equipment. Indoor levels typically range from 20 to 80 percent of outdoor levels, but have been shown to reach levels that exceed a Stage 1 smog alert level when some types of ozone-generating "air cleaners" are used. Breathing elevated concentrations of ozone can be harmful to health, especially for active people, including children. Whether inhaled indoors or outdoors, ozone can irritate the respiratory tract, which can cause coughing, wheezing, and pain on deep breathing. Ozone also can exacerbate asthma, particularly those with concurrent allergen exposure. Ozone masks the odor of other indoor pollutants by deadening the sense of smell. It also reacts with certain indoor pollutants to produce toxic by-products, including formaldehyde and ultrafine particles.

Toxic Air Contaminants and Other Indoor Air Pollutants

Other pollutants can occur at elevated levels indoors due to emissions from indoor sources. Some have been identified by the ARB as toxic air contaminants (TACs), air pollutants other than traditional (criteria) pollutants that can contribute to an increase in death or serious illness.

- **Volatile organic compounds (VOCs)** – As mentioned above, VOCs such as formaldehyde and chlorinated solvents are common in indoor air, and can exacerbate asthma and cause cancer and irritant effects. Some of these chemicals also have reproductive, developmental, and neurological effects at very high levels encountered infrequently in non-industrial workplaces. Indoor levels of formaldehyde, a pungent smelling gas, nearly always exceed chronic health-based guideline levels and acceptable cancer risk levels. Formaldehyde is emitted from numerous indoor sources including building materials (especially pressed wood products), composite wood furnishings, personal care products, cosmetics, permanent pressed clothing, combustion sources, and some new carpet pads and adhesives.

- **Environmental tobacco smoke (ETS)** – ETS causes cancer, heart disease, asthma episodes, middle ear infections in children, sudden infant death syndrome (SIDS) and other adverse effects. ARB and OEHHA (2004/2005) currently estimate that exposure to ETS results in about 400 excess lung cancer deaths, 1700-5500 heart disease deaths, and more than 31,000 asthma episodes per year in children (these estimates are currently under scientific peer review). These estimates would be expected to decrease over time, due to the substantial reductions in smoking and ETS exposure in California. Nonetheless, despite decreases in the percent of smokers in the population and the statewide prohibition of smoking in workplaces, some individuals, especially children, are still exposed to elevated levels of ETS in the homes and vehicles of smokers.

- **Polycyclic aromatic hydrocarbons (PAHs)** – PAHs, emitted from combustion sources such as cigarettes, woodstoves and fireplaces, include a number of known or suspected carcinogens. They have been found to adsorb onto particles in the air and deposit onto carpets, from which they can be resuspended during vacuuming or other activity.

- **Radon daughters and asbestos** are other known lung carcinogens found indoors in some California environments. Both radon and asbestos are naturally-occurring, each emanating from specific types of soils. Radon levels in California are typically lower than mitigation guideline levels. Nonetheless, as discussed above, a preliminary estimate indicates that radon may contribute to 1500 excess lung cancer deaths in California per year. However the risk from radon cannot be fully separated from that of tobacco smoke, and reduction of exposure to tobacco smoke remains the primary mitigation approach. Indoor asbestos is elevated only infrequently, typically during remodeling of older buildings. Naturally-occurring asbestos has been measured recently in a few areas of California, and has resulted in some mitigation actions.

- **Pesticides and metals** – Dust from surfaces and carpets in homes and schools have been shown to contain numerous residues of pesticides, lead, mercury and other long-lasting contaminants that have originated from outdoor activities, cigarettes, fireplaces, and other sources. This is of special concern for very young children, who spend time on the floor, and put their hands in their mouths, because ingestion is often the primary route of exposure**.** Pesticides are widely used, and some can cause adverse developmental and neurological effects at elevated exposure levels. Many pesticides registered for use today are short lived, yet some are persistent in the environment, lasting 20 or 30 years or more. Recent studies indicate that some pesticides may be more persistent in indoor environments, because they do not experience the effects of weather and sunlight.

Biological Contaminants

Biological contaminants include substances of plant, animal, or microbial origin, such as bacteria, viruses, mold, pollen, house dust mites, animal dander; biological toxins such as endotoxins and mycotoxins, and microbial volatile organic chemicals. These biological agents are abundant in both indoor and outdoor environments, but are considered contaminants when found in undesired locations or at elevated concentrations. Excessive exposure to these contaminants can be associated with mucous membrane irritation (which may cause symptoms such as itchy eyes, runny nose or sore throat) or hypersensitivity reactions such as asthma attacks or allergy symptoms in sensitive individuals. Some individuals in persistently damp buildings report a variety of symptoms such as headache, memory difficulties, vomiting, and diarrhea; some researchers postulate that exposure to biological toxins may induce such symptoms. In a recent Institute of Medicine report (IOM, 2004), scientists found a number of symptoms and illnesses associated with dampness in buildings and with indoor mold, although the scientific evidence was not yet considered sufficient to confirm a causal relationship.

Many communicable diseases are primarily transmitted from person to person in indoor air. Common viral infections such as influenza, measles and chicken pox, as well as emerging diseases such as Severe Acute Respiratory Syndrome (SARS), are spread through inhalation of virus-contaminated droplets produced when an infected person coughs or sneezes, or from touching a surface or object contaminated with infectious droplets and then touching one's mouth, nose, or eyes (CDC, 2004). Tuberculosis is a notorious infectious disease that is transmitted in closely occupied spaces. Building-related illness (BRI) refers to an illness for which the specific cause can be identified within the building, such as bacteria in ventilation systems causing Legionnaires' disease, or humidifier fever. The usual causes of BRI include viruses, bacteria, and fungi. BRI impacts can be substantial, and are of increasing interest as the role of buildings in promoting diseases of biological contaminants becomes better understood.

III. INDOOR CONCENTRATIONS AND PERSONAL EXPOSURES

Indoor concentrations of many pollutants sometimes exceed health-based guideline levels or standards. Some pollutants, like formaldehyde, nearly always exceed recommended levels. Studies conducted by the ARB, the U.S. EPA, and others also have shown that indoor levels of VOCs and some other pollutants are often higher than outdoor levels.

More importantly, people's "personal exposures" to pollutants, especially to VOCs, are often greater than both indoor and outdoor pollutant levels. Personal exposures to some pollutants are elevated because people spend time very near sources of pollutants, such as when using a gas stove, cleaning solutions, or personal care products. During such activities, the product emissions are most concentrated very near the person. Pollutants become more diluted in the air as distance from the source increases. Consequently, for VOCs and many other pollutants, personal exposure levels are most closely correlated with indoor concentrations.

Indoor – Outdoor Relationships

There is continuous air exchange between indoor environments and the outdoors. Outdoor emissions readily infiltrate into indoor environments, and indoor emissions seep outdoors and can contribute to outdoor air pollution. For example, ozone formed outdoors and fine particles and other emissions from nearby motor vehicles typically penetrate indoor environments to varying degrees, depending on the rate of air exchange, degree of filtration, and other factors. For residential buildings, the main entry routes of outdoor air are open windows and doors, gaps in the building shell, and devices such as swamp coolers that move outdoor air indoors. For large public and commercial buildings, the main entry route is through the mechanical heating, ventilating, and air conditioning (HVAC) systems, which actively move outdoor air indoors and typically filter some of the particles from the air. Any pollutants in the air just outside the building may thus be brought into the indoor space. Indoor pollutant levels can be much higher than those outdoors when indoor sources are present and the air exchange rate is low.

Similarly, indoor pollutants can flow through windows and penetrate small gaps in the building shell to contribute to the local outdoor burden of pollution. Emissions from certain sources used indoors, such as paints, consumer products, and gas and woodburning appliances contribute to local outdoor pollution levels, either through direct emissions or, in the case of reactive volatile organic chemicals, through chemical reactions.

Environmental Justice Considerations

ARB adopted an environmental justice policy in 2001. This policy requires the fair treatment of all people regardless of gender, ethnicity, and socioeconomic status. The limited research available indicates that some segments of the population may be disproportionately exposed to indoor pollutants. In California, African Americans, American Indians, and Alaska natives experience a higher prevalence of lifetime asthma (Meng *et al.*, 2003). However, in general, the prevalence of asthma appears to be more strongly correlated with lower socioeconomic status than with race and ethnicity (IOM, 1993). Dust mites, cockroaches, and mold are important asthma triggers that are more likely to be present in locations where lower income individuals most often live. Additionally, research indicates that blood lead levels are higher for poor and minority children in central cities. Formaldehyde levels have been highest in mobile homes, which are more often occupied by lower income families.

The ARB has taken steps to address some of these issues. Special air monitoring studies have been conducted at schools in some communities, and a large asthma study is underway. Fact sheets for public outreach have been published in English and Spanish. Efforts are underway to limit formaldehyde emissions from composite wood products through an Air Toxics Control Measure. Pursuit of indoor mitigation measures can further help reduce any disparities in exposure and health impact that may exist among different groups of the population.

Non-industrial Workplaces

Non-industrial workplaces often provide unique situations for exposure to indoor air pollutants. Products and activities associated with non-industrial workplaces such as beauty salons, hospitals, dry cleaners, medical laboratories, jails, photocopy centers, aircraft cabins, indoor sports arenas, retail shops, copy shops, and other workplaces can lead to elevated levels of air pollutants and indoor environmental concerns. Despite Cal/OSHA's regulations for pollutant levels and ventilation requirements, some workers in these environments experience adverse health effects related to indoor environmental quality. Additionally, many of these locations are regularly visited by members of the public.

Cal/OSHA has various regulations to address ventilation and personal exposures, but most indoor air quality complaints arise in non-industrial workplaces, where preventive controls are not normally utilized. A review of Cal/OSHA inspection data indicates ventilation requirements are often not met. From 1995 through 2001, citations for ventilation violations were issued during 519 on-site inspections. Of these citations, the majority (260) were in services, with 114 in schools and 33 in health care. A substantial number of citations were issued for other indoor air quality violations as well, but there are inconsistencies in recordkeeping, making it difficult to analyze for indoor air qualiy concerns. However, from 1997 through 1999, 849 workplace inspections were coded as indoor air investigations, and Cal/OSHA has indicated that the actual number of indoor air quality related inspections may be more than twice that number.

IV. COSTS OF INDOOR POLLUTION

Indoor air pollution takes a significant toll on Californians' lives and has significant economic costs. Exposure to indoor pollutants results in premature death and increased disease, increased expenditures for health care, decreased worker productivity, and decreased learning by school children. Table ES-2 shows estimates of the costs of indoor air pollution in California that are currently quantifiable. It includes the valuation of health (cost of premature death), an estimate of the increased expenditures for health care, and an estimate of some of the costs associated with reduced worker productivity. Because of the limited amount of information available for accurately estimating indoor pollution costs and the broad range of effects and resultant costs, there is considerable uncertainty in the cost estimates shown. Most importantly, the costs of many known or suspected indoor pollution impacts cannot currently be quantified due to lack of cost data and/or sufficiently quantified population exposure data. For example, the costs for the impacts of biological contaminants and indoor PM-related illness and disease are likely to be very high, potentially in the billions of dollars, but are not yet quantifiable. Additionally, while ETS has been well-studied and its impacts and costs can be reasonably quantified, the impacts and costs for some other toxic indoor pollutants have been less studied and cannot be quantified at this time.

The combined cost of both fatal and non-fatal impacts due to indoor air pollution in California homes, schools, and non-industrial workplaces is substantial: it is estimated to be **$45 billion per year.** As shown in Table ES-2 and discussed in Section 3 of this report, the annual valuation of premature deaths attributable to indoor air pollution is estimated to total about $36 billion, with most stemming from ETS and radon. OEHHA's most recent ETS risk estimates are currently under review by the Scientific Review Panel, and may change somewhat before this report becomes final. The actual total valuation of premature deaths is likely to be higher than the $36 billion presented here because these estimates do not include the impacts of other pollutants that may increase the risk of premature death, such as other carcinogens emitted from materials and products, and PM from cooking, wood smoke, and other indoor combustion sources.

Table ES-2. Summary of Estimated Costs of Some Indoor Air Pollution in California

Health End Point	Health Valuation: Premature Death[1-3] ($ Billions/yr)	Medical Cost[2-4] ($ Billions/yr)	Lost Productivity Cost[2,3] ($ Billions/yr)	Total Cost ($ Billions/yr)
CO: poisoning	0.15	<0.001	NA	0.15
VOCs: cancer	0.73	0.011	NA	0.74
ETS: lung cancer	2.4	0.025	NA	2.4
ETS: heart disease	23	0.055	NA	23
ETS: asthma episodes	NA	0.020[5]	NA	0.020
ETS: low birth weight	NA	0.19	NA	0.19
ETS: otitis media	NA	0.019[5]	NA	0.019
Radon: lung cancer	9.5	0.097	NA	9.6
Mold and moisture: asthma and allergies	0.031	0.19[5]	NA	0.22
Sick building syndrome	NA	NA	8.5	8.5
TOTAL[6]	**36**	**0.6**	**8.5**	**45**

1. From Table 3.2.
2. Estimates are based on average or mid-point of incidence rates of death and disease from previous tables, and estimates of productivity discussed in the text. Values are rounded to two significant figures.
3. Original data were adjusted to year 2000 dollars and year 2000 population, except where noted otherwise in previous tables.
4. From Table 3.3.
5. Includes indirect costs such as lost work days, lost school days, and travel expenses.
6. Totals are rounded to two significant figures. These totals are likely low because conservative cost estimates were used, and quantitative information is not readily available for many known impacts of indoor air pollution, such as for indoor PM and many indirect costs of health effects.

The quantifiable medical costs (direct and some indirect) due to indoor air pollution total more than $0.6 billion per year, with a large portion of the costs attributable to mold and other moisture-related allergens. These cost estimates for morbidity do not include the potential losses due to other impacts such as those from other indoor allergens, the long-term effects of CO poisoning, reduced student performance, lost earnings opportunity, unpaid caregivers, and human suffering. Finally, the cost of reduced worker productivity due to indoor air pollution (primarily sick building syndrome) that could be prevented is estimated to be about $8.5 billion per year.

V. EXISTING REGULATIONS, GUIDELINES AND PRACTICES

Despite the significant health effects and potential economic impacts caused by indoor sources of pollution, there are few government standards restricting emissions from common sources of indoor pollutants, and there is no comprehensive program to protect air quality within residences, schools, or public and private buildings. A variety of agencies and organizations have established standards and guidelines that can be applied to limited aspects of indoor environments to assist in the assessment and control of health hazards from air pollutants. Foremost among these are workplace standards; however, those standards are designed for 8-hour exposures of healthy adults, are not as protective as standards set for ambient air, and are not designed to be protective of the more sensitive subgroups of the population, such as children. Other standards are applicable to indoor air quality, but only in a limited way. For example, the ambient air quality standards and emission control regulations indirectly improve IAQ by improving ambient air quality, and Assembly Bill 13 (1995) prohibits cigarette smoking, in workplaces. Although many of these programs have resulted directly or indirectly in improvements in indoor air quality, they do not ensure healthful indoor air quality.

- **Workplace Standards.** The California Occupational Safety and Health Program (Cal/OSHA) in the Department of Industrial Relations (DIR) has authority to develop, promulgate, and enforce air pollutant exposure limits, ventilation regulations, and other standards for the workplace that directly impact indoor air quality. The California Occupational Safety and Health Standards Board is the unit within the Cal/OSHA program with authority to adopt standards and regulations to protect workers. Some of the Cal/OSHA standards and regulations that impact indoor air quality are the following:

  ✓ **Permissible Exposure Limits**. The Standards Board sets permissible exposure limits (PELs) and other limits for airborne contaminants. The PELs are 8-hour exposure limits generally protective of the health of most workers. However, they are not designed to protect vulnerable members of the population such as infants, the elderly, or individuals with pre-existing heart or respiratory disease. Additionally, they are not intended to be protective for exposures greater than eight hours per day, five days a week, and PELs are not available for all indoor air contaminants.

  ✓ **Ventilation**. Cal/OSHA requires employers to maintain and operate mechanical ventilation systems to provide at least the quantity of outdoor air required by the State Building Code at the time the building permit was issued.

  ✓ **Mold, moisture**. Cal/OSHA requires that workplaces be maintained in a sanitary condition, and that employers correct all types of water intrusion or leakage, to reduce the potential for mold growth.

- **Ventilation design requirements.** Minimum ventilation levels for the design quantity of outdoor air in new non-residential buildings, such as offices and public buildings, have been established by the California Energy Commission for different types of buildings and different types of rooms (e.g., conference rooms vs. offices). The Commission also sets energy efficiency standards for residences, which has resulted in reduced infiltration of outdoor air, or “tightening” of new homes compared to older homes. This has implications for indoor air quality, and the Commission is funding research to assess the need for revisions to the standard to assure healthful IAQ in homes.

- **Anti-smoking law**. Cigarette smoking, a major source of indoor pollution, is prohibited in nearly all public buildings in California. A statewide, smoke-free workplace law passed in 1995 (AB 13) eliminated smoking in nearly all California indoor workplaces–including restaurants, bars and gaming clubs–and spurred a reduction in smoking by the California population. The ban has been very successful in reducing worker exposure to cigarette smoke. In 1999, 93 percent of California's indoor workers reported working in a smoke-free environment, compared to only 45 percent in 1990 (Gilpin *et al.*, 2001). The prohibition of workplace smoking, along with the Department of Health Services Tobacco Control Program, have both had far reaching benefits. In 1994, 63 percent of Californians with children did not allow smoking in the house; by 2001, 78 percent did not allow it (Gilpin *et al.*, 2001). Additionally, smoking rates among California adults declined from 26 percent to 17 percent between 1984 and 2001 (BRFSS, 2001).

- **State and national ambient air quality standards** (AAQS) and control programs**,** established by the ARB and U.S. EPA, respectively, are developed to protect the general public from the harmful effects of "traditional pollutants" in outdoor air, for specified averaging times (exposure times). California's AAQS are often more protective than the national AAQS. Currently, the State AAQS are under review to ensure that they are protective of sensitive populations, especially infants and children (ARB/OEHHA, 2000). In the absence of indoor air quality standards or guidelines, the AAQS serve as useful guideline levels for those pollutants indoors, because they are based on specified averaging times and incorporate a margin of safety. Both the California and federal AAQS are listed at http://www.arb.ca.gov/research/aaqs/aaqs.htm.

- **Consumer product standards**. The federal Consumer Product Safety Commission (CPSC) has jurisdiction over consumer products, except for pesticides, cosmetics, tobacco and cigarettes, food, drugs, automobiles, and a few others. CPSC has authority to ban a product, establish mandatory safety standards, recall products for repair or replacement, require warning labels, or develop voluntary standards in conjunction with manufacturers. However, CPSC is primarily focused on addressing safety issues, and most often uses voluntary processes and labeling requirements.

  The ARB also regulates consumer products, for the purpose of reducing smog in California. An additional benefit is a reduction in the amount of certain types of VOCs that are released in homes and institutions. In addition to reducing the reactive VOC content of products, ARB has prohibited the use of several toxic air contaminants in 13 categories of products, resulting in reduced indoor emissions of those substances. Reducing reactive VOC emissions and toxic pollutants from cleaning compounds, polishes, floor finishes, cosmetics, personal care products, disinfectants, aerosol paints, and automotive specialty products has likely reduced personal exposures to those VOCs as well.

- **Local woodburning ordinances.** Several communities in California have recently implemented woodburning ordinances or policies to reduce smoke emissions in their communities. For example, in the San Francisco Bay area, 24 cities have ordinances that prohibit conventional fireplaces in new construction. The mountain town of Truckee has a more aggressive policy that states that existing unapproved wood burning appliances must be removed from all properties by July 15, 2006. The San Joaquin Valley Air Pollution Control District issues daily advisories on restrictions for residential wood burning.

- **Guidelines and Public Education.**

  ✓ OEHHA has developed **acute and chronic reference exposure levels (RELs)** as guidelines to prevent harm from toxic air pollution, under the Air Toxics "Hot Spots" Information and Assessment Act of 1987 (HSC Section 44300 *et seq)*. Although established to identify healthful limits for outdoor air near industrial sources, RELs have been used for indoor pollutants as indicators of potential adverse health effects other than cancer. OEHHA has established chronic RELs for 79 air pollutants to define healthful levels for exposures that can last 12 years or more (OEHHA, 2003a), and acute RELs for 51 chemicals to define healthful levels for exposures of one hour (OEHHA, 2000a). OEHHA also has developed an 8-hour, interim indoor REL (IREL) for formaldehyde of 27 ppb, specifically for indoor application. This IREL identifies the level below which effects such as eye, nose, and throat irritation would not be expected to occur during typical daytime (8-hour) occupancy of buildings.

  ✓ **ARB's Indoor Air Quality Guidelines** have been developed to advise the public regarding the health effects and indoor sources of key indoor pollutants, and what the public can do to reduce their exposures. Some AAQS are used as recommended maximum exposure levels in ARB's *Combustion Pollutants Guideline*. ARB's guidelines for formaldehyde and chlorinated solvents recommend achieving as low a level of those pollutants as possible indoors, because they are carcinogenic, and there are no known levels that are absolutely safe.

  ✓ **DHS and other agencies** have developed various guidelines that can be applied to improve indoor environments. DHS published guidelines for reducing VOCs in new office buildings in 1996, played a key role in the development of Section 01350 emissions limits for materials used in state buildings and schools, and has been directed to develop guidelines to prevent and remedy mold problems in buildings. The California Energy Commission spearheaded the formation of the Collaborative for High Performance Schools (CHPS), which has developed *Best Practices Manual* that include guidance for selecting building materials with reduced indoor pollutant emissions. The U.S. EPA has developed its *IAQ Tools for Schools Program* to provide guidance for assuring healthful indoor air quality in schools. All of these and ARB's indoor air quality guidelines are available at no charge on the Internet.

  ✓ **Industry and professional groups** have developed numerous guidelines for improving indoor air quality. Examples include the building ventilation requirements of the American Society of Heating, Refrigerating, and Air-conditioning Engineers' (ASHRAE), the product emissions criteria of the Carpet and Rug Institute's (CRI) Green Label and Green Label Plus Programs, and voluntary formaldehyde emission limits of the Composite Panel Association and the Hardwood Plywood and Veneer Association. The industry and professional guidelines vary in their degree of IAQ protection, but are widely used and generally have helped reduce some indoor pollutants over the years.

VI. METHODS TO PREVENT AND REDUCE INDOOR AIR POLLUTION

There are a number of methods that can be used to prevent or reduce indoor air pollution. The most effective approach is to remove or reduce indoor emissions by using building materials, consumer products, and appliances that emit little or no air pollution. Ventilation (including proper exhaust ducting) and public education also are important components of a strong indoor air quality improvement program. Air cleaning devices (air filters and air cleaners) can be helpful in certain situations; however, their effectiveness is often limited, and some air cleaners actually release ozone into the indoor environment, adding to the indoor pollutant burden.

> **Minimizing indoor emissions is generally more effective than removing them after emission has occurred.**
>
> *T.J. Kelly, Battelle, Indoor Air Quality Symposium: Risk Reduction in the 21st Century, Sacramento, May, 2000*

- **Source control** is the most reliable approach to prevent indoor pollution because it does not depend on building maintenance or other human actions to assure healthful indoor air (NRC, 1981). Source control includes source substitution, source removal, and source modification. Reduction at the source is most effectively achieved through use of low- or zero-emitting appliances, products or materials, or reformulation of chemical products. For example, indoor formaldehyde levels can be greatly reduced by using building materials that emit little or no formaldehyde, instead of materials made with urea-formaldehyde resins. Low emission product designs or reformulations can usually be accomplished by the manufacturer, with minimal impact on the consumer, often with only minor increased costs.

- **Ventilation** is a standard engineering approach to assuring good indoor air quality and comfort. Ventilation removes and dilutes indoor contaminants, removes moisture from the air which helps to prevent mold growth, and removes body effluents such as carbon dioxide that lead to a stuffy environment. Natural ventilation, through open windows and doors, is the primary ventilation route for residences, while mechanical ventilation, using HVAC systems, is most common in commercial buildings. Adequate and effective ventilation, and ducting of exhaust from combustion appliances, are necessary for acceptable indoor air quality, even when known air contaminants are minimized. However, ventilation is not a complete solution to indoor pollution: ventilation consumes energy, and some pollutants, such as formaldehyde emitted from building materials, require years to off-gas and are not completely removed by ventilation.

- **Proper operation and maintenance of buildings** is critical to achieving and maintaining healthful air quality in buildings. Ventilation systems should be maintained as intended and filters replaced routinely to prevent soiling and the growth of mold and bacteria in the ventilation system and in the occupied space. Roof leaks that are not repaired promptly can lead to moisture intrusion and mold growth. Regular cleaning of indoor spaces with proper cleaning methods can reduce biological contaminants, such as those associated with insects and pollen, as well as persistent chemicals. Inattention to proper operation and maintenance will not only lead to poor indoor air quality, but can also prove more costly in the long term due to increased costs to remedy the larger problems that result.

- **Public education** is a key step for reducing Californians' exposures to many indoor air pollutants. People's choices and activities have a major impact on their exposures to air pollution. The use of various consumer products, and activities such as cigarette smoking and cooking can result in significant indoor releases of pollutants. However, public education alone is not a complete solution. Some groups of the population cannot respond appropriately to take needed action. For example, children cannot read or understand all written information that is provided; elderly people living in group settings cannot control the products used in their facility; and low-income families may not be able to afford safer alternatives.

- **Air cleaning devices** can also help improve indoor air quality; however, their effectiveness is often limited. Air cleaning devices include both central air filters and portable air cleaning appliances. Air filters are a normal component of mechanical HVAC systems in public and commercial buildings. High efficiency particulate arrestor (HEPA) filters, though not commonly used in commercial buildings, are most effective at removing particles from outdoor air as it is brought indoors. Air cleaning appliances are usually portable units used indoors to remove particles from the indoor air, although a few remove gases, and some remove both particles and gases. Mechanical air cleaners typically draw air through a filter while electronic air cleaners remove pollutants with the use of an electric charge. Electrostatic precipitators (ESPs) and ionizers are the two major types of electronic air cleaners on the market.

  The proper air cleaner may help control airborne particles in some situations; however, the limited scientific evidence available has not documented any health benefits from air cleaners. Additionally, ESPs and ionizers can produce ozone as a by-product; thus proper use and maintenance are critical to prevent harmful levels from developing when using these devices.

  Air cleaners that intentionally generate ozone should not be used indoors (ARB, 2005; DHS, 1998; ALA, 1997). Independent studies by the U.S. EPA, the Consumers Union, and others have shown that ozone-generating air cleaners do not effectively destroy microbes, remove odor sources, or reduce indoor pollutants enough to provide any health benefits. These devices can emit very high amounts of ozone – several times the state ambient air quality standard – but they are currently unregulated.

Ozone-generating Air Cleaners

"These machines are insidious. Marketed as a strong defense against indoor air pollution, they emit ozone, the same chemical that the ARB and USEPA (U.S. Environmental Protection Agency) have been trying to eliminate from our air for decades."

Barbara Riordan, interim ARB Chairperson. California Air Resources Board, Press Release 05-02, Sacramento, January 2005.

VII. PRIORITIZATION OF INDOOR SOURCES BASED ON EXPOSURE AND ADVERSE IMPACTS

Reduction of public exposure to the many indoor air pollutants is most effectively achieved by reducing pollution at the source. Tables ES-3.1 and ES-3.2 suggest a prioritization scheme for implementation of mitigation measures, by source categories. The source categories have been ranked into two groups–high and medium priority–and are listed alphabetically within each ranking group. The primary factors considered in prioritizing the source categories include the extent of the population's exposure to the sources and their emissions, the relative reduction in health impacts that could be achieved with further action beyond any already undertaken, ease of mitigation, and trends in emissions from and use of source categories. A quantitative prioritization was not undertaken because such an effort is well beyond the scope of this report. Such an effort would be an appropriate step prior to taking action under a comprehensive program to address indoor sources. Additionally, the preliminary indoor air pollution cost estimates provided in this report were considered, but were not weighted heavily in the prioritization because they primarily reflect the availability of cost information and the length of time a given pollutant, such as ETS and radon, has been studied, not necessarily the actual extent of exposure and risk in California.

Table ES-3.1. High Priority Source Categories for Mitigation [1]

SOURCES OF POLLUTANTS[2] (listed alphabetically)	**EXAMPLES OF POLLUTANTS**[3] **EMITTED**	**POTENTIAL APPROACH TO MITIGATION**[4]	**DIRECT STATE AUTHORITY TO TAKE IAQ MITIGATION ACTIONS**
Air Cleaners (ozone-generating)	Ozone	Emission limitations	No
Biological Contaminants (mold, pollen, bacteria, viruses, house dust mites, cockroaches)	Particles, allergens, asthma triggers, toxins	Requirements for habitable spaces; require certification of mold assessors and mitigators	Limited
Building Materials & Furnishings (particle board, plywood, paneling, flooring, caulk, adhesives, new carpet assembly, furniture)	Formaldehyde, acetaldehyde, benzene derivatives, acrylates, naphthalene, phenol, some other VOCs	Emission limitations, product use restrictions, market incentives	Limited (some indirect)
Combustion Appliances (gas & propane stoves, ovens, furnaces, heaters; woodstoves and fireplaces)	Carbon monoxide, nitrogen oxides, particles, soot, polycyclic aromatic hydrocarbons	Emission limitations, active exhaust ventilation, safety devices, product use restrictions, product re-design, improved venting	No
Environmental Tobacco Smoke (cigarettes, cigars)	Particles, polycyclic aromatic hydrocarbons, benzene, carbon monoxide, some other VOCs	Focused parent education; reduce smoking in homes and vehicles	Yes, workplaces No, private homes and vehicles
Radon (soil, rock, ground water, building materials containing radium)	Radionuclides, radon gas	Screening measurements, building codes	Limited

1. Individual sources may be higher or lower than the source category ranking.
2. All of the examples of pollutant sources may not emit all of the pollutants listed in the corresponding box in column two.
3. Air pollutants may be identified as Toxic Air Contaminants (TACs) by the California Air Resources Board, and/or identified as Proposition 65 chemicals; or, criteria (traditional) air pollutants.
4. Public education, economic incentives, and non-regulatory approaches should also be used where appropriate. The actual approach taken would be determined after extensive discussions with the relevant industries, in consideration of costs, feasibility, and effectiveness.

Tables ES-3.1 and ES-3.2 also suggest potential approaches for mitigating the pollutants and sources listed. Emission reductions should be accomplished at the manufacturing, distribution, or construction stage. Alternatives or mitigation options are currently available for most of the sources listed. Emission limitations achieved at the manufacturing stage, such as reducing toxic contaminants in building materials, would be effectively invisible to the consumer and assure exposure reduction. For example, low-emitting carpets, no-formaldehyde furniture, and non-toxic cleaning products are currently sold in the marketplace. Alternative products or formulations must be recommended with care, however: substitutes should not result in increased emissions of, or exposures to, other toxic pollutants.

Finally, Tables ES-3.1 and ES-3.2 include a column indicating whether direct authority exists at the state level to take the mitigation actions listed in column three. For most source categories, there is no state agency with clear, direct authority to take the mitigation actions indicated. In some categories, one or more agencies has limited authority to address a small portion of the sources included. For example, if needed, Cal/OSHA could impose product use restrictions or require other actions to reduce worker exposure to institutional cleaning product emissions. However, neither Cal/OSHA nor any other state agency has direct authority to restrict pollutant emissions from cleaning products for the purpose of reducing indoor air concentrations and exposures. In other cases of limited authority, the benefits to indoor air are incidental results from actions taken under the agency's primary authority, or mitigation actions required to avoid negative impacts from regulations.

The specific rationale for the ranking of each category is briefly discussed below. Note that some individual sources within the group may have a higher or lower priority. A more detailed assessment would be needed to prioritize specific products within these larger categories.

High-Ranked Source Categories

- **Air cleaning devices or "air purifiers" that generate** ozone can produce unhealthy levels of ozone in indoor environments. Some devices marketed as air cleaners purposely release ozone, which can result in ozone concentrations several times the State standard, and directly harm sensitive occupants. Additionally, these air cleaners are ineffective at cleaning the indoor air. Many effective alternatives are available in the marketplace. Additionally, ionizers and electrostatic precipitators emit ozone to varying degrees as a by-product of their function, and such emissions may need to be limited. The market for air cleaners has increased substantially in recent years, and is expected to continue to expand (Freedonia, 2004).

- **Biological contaminants** are a high priority because of their ubiquitous presence and their widespread health and fiscal effects. Animal dander, pollen, house dust mites, and cockroaches cause millions of sensitive individuals to experience allergy symptoms and asthma attacks. Indoor mold has been an increasing problem in recent years, costing substantial sums of money for remediation and lawsuit settlements. Bacteria such as *Legionella* cause both serious and mild illness. Disease transmission can occur because infectious agents are emitted into the indoor environment. Infectious disease transmission is increased in indoor environments with crowded or dirty conditions and insufficient outdoor airflow. Mitigation actions for mold and some other biologicals might include required annual inspections and remediation in public buildings, group homes, and rental units, and in private homes at the time of sale. Certification requirements for mold assessors and remediators and other IAQ consultants would help assure the quality of inspections and remediation.

- **Building materials and furnishings** are a high priority for mitigation because they often emit multiple toxic air pollutants, especially when new, and have a high loading level in indoor environments, resulting in high exposure levels for occupants. A substantial percent of the population is exposed to such emissions due to the continued high rate of new building construction in California and the increasing number of home renovations undertaken by homeowners. Emission limits for pollutants emitted from building materials and furnishings (formaldehyde being the most predominant) would benefit all indoor environments and has potential for significant health benefits due to reduced incidence of asthma exacerbation, cancer, and eye, nose and throat irritation.

  Low-emitting alternatives are available. For example, non-wood alternatives and composite wood products made with phenol-formaldehyde resin have much lower formaldehyde emissions than composite wood products made with urea-formaldehyde resin, and could be substituted for some applications. In cabinets and furniture, all surfaces of these products can be coated or laminated to substantially reduce formaldehyde emissions. Building materials are currently available that meet Section 01350 emission requirements for formaldehyde and other chemicals of concern. A list of products for use in school construction projects that meet these requirements is available at http://www.chps.net/manual/lem_overvw.htm. These alternatives materials are available and should be required in public buildings, group homes, schools, and other buildings.

- **Combustion appliances** are also a high priority for mitigation. They can emit carbon monoxide, nitrogen dioxide, polycyclic aromatic hydrocarbons, particles, and other pollutants. These pollutants can have severe acute health effects including respiratory effects and exacerbation of asthma, and contribute to cancer risk. Reduced exposure to pollutants from gas and propane appliances, whether it be through emission limitations, active exhaust ventilation, or both, could have immediate widespread benefits for occupants in environments with such appliances. Precedence for mitigation of appliance emissions has been set in the state's low-income weatherization program.

  Statewide measures to reduce emissions from woodstoves and fireplaces both indoors and outdoors also are highly desirable. Such measures could have a major impact on improving both community-wide indoor and outdoor air quality in many areas of the state. Emission limitations, product re-design, product use restrictions, and improved venting can be used for reducing this type of pollution. A number of local government entities have recently approved regulations restricting the use of woodstoves and fireplaces: in the San Francisco Bay area, 24 cities have ordinances that prohibit conventional fireplaces in new construction. The mountain town of Truckee has a more aggressive policy that requires that existing unapproved wood burning appliances be removed by July 15, 2006. The San Joaquin Valley implemented a daily advisory for restrictions on residential fireplace or wood stove use on January 1, 2004 (http://www.valleyair.org/BurnPrograms/wood_burning.htm). Woodsmoke especially impacts those with asthma and other respiratory disease.

- **Environmental tobacco smoke** has been greatly reduced in California, primarily due to legislation that bans smoking at the workplace. However, children's exposures remain a special concern, because they can be highly exposed when smoking occurs in their home or in vehicles driven by family or friends who smoke. Actions to reduce children's exposure–such as an increased focus of public education on smoking parents, and reduction of smoking inside vehicles and homes with children–remain a high priority.

- **Radon** is ranked as a high priority due to its high estimated lung cancer risk. However, indoor levels in California are generally below the recommended mitigation level, and the need for mitigation is very building- and area-specific. The risk from radon is strongly associated with smoking (NRC, 1999a). Mitigation might include revised building codes and requirements for testing and implementation of construction changes, if needed, upon the sale of a home or building in areas with elevated radon levels. The California Department of Health Services (DHS) has established a list of certified providers of radon services.

Medium Ranked Source Categories

The pollutant source categories included in Table ES-3.2 are lower in priority than those above, but nonetheless include some sources that warrant consideration for mitigation.

- **Architectural coatings,** such as paints and lacquers, are available in "low VOC" versions due to formulation changes targeted toward reducing outdoor ozone. However, they are not directly regulated by the state. ARB develops Suggested Control Measures and provides guidance and technical assistance to air quality management districts in the state, 22 of which have adopted rules to reduce VOC emissions from coatings. Like building materials, architectural coatings are widely used and have a high loading in indoor environments when used, due to the large surface areas they typically cover. Additionally, some components of coatings can be harmful, but may not necessarily be addressed through reactive VOC reductions. However, because reductions have been achieved in districts that cover 95 percent of the California population, this source category is ranked as a medium priority.

- **Consumer products and personal care products** have been regulated by ARB to reduce emissions of reactive VOCs in order to reduce outdoor smog formation. Reactive VOCs, and some toxic air contaminants, have been reduced substantially through reformulation of a number of product categories. For example, in reducing VOC content to comply with ARB regulations, manufacturers often use water-based technologies and use VOC exempt compounds such as acetone. To prevent increased use of TACs, ARB has prohibited the use of perchloroethylene, methylene chloride, and trichloroethylene in 13 categories including general purpose degreasers, brake cleaners, all spray paints, all aerosol adhesives and adhesive removers. Additionally, antiperspirants and deodorants are not allowed to contain any compounds identified as TACs. The Board recently approved a rule to remove *para*-dichlorobenzene from solid air fresheners and toilet/urinal care products.

  However, despite the breadth of products addressed under ARB's consumer products regulations, not all types of consumer products have been regulated. Also, due to the nature of some products (household cleansers, air fresheners, stain removers, etc.), the user is in close proximity to the release of chemicals during use, and can experience high pollutant exposure when using the product. Thus, there is an apparent need to reduce emissions from consumer products to prevent high personal exposures and risks, and to address types of products not currently regulated under ARB's programs. Chemical reformulations, emission limitations, content limits, and/or product use restrictions of consumer products are mitigation approaches that could result in further significant risk reductions, especially for product users. Because of the ARB's progress to date with chemically formulated products, some of the highest emitting consumer products have been reformulated, and therefore this category is ranked medium rather than high.

Table ES-3.2 Medium Priority Source Categories for Mitigation [1]

SOURCES OF POLLUTANTS[2] (listed alphabetically)	EXAMPLES OF POLLUTANTS[3] EMITTED	POTENTIAL APPROACH TO MITIGATION[4]	DIRECT STATE AUTHORITY TO TAKE IAQ MITIGATION ACTIONS
Architectural Coatings (e.g., paints, sealants, lacquers, varnishes)	Formaldehyde, acetaldehyde, ethylene glycol, metals, others	Emission limitations, chemical reformulations, use restrictions to reduce TACs & nonreactive VOCs with health impacts;	No
Consumer Products (e,g.,household and institutional cleaners, furniture- and floor-care products, air fresheners, stain removers, detergents) **Personal Care Products** (e,g.,products used for hair and skin care)	Methylene chloride, para-dichlorobenzene, perchloroethylene, toluene, benzene, naphthalene, formaldehyde, acetaldehyde, metals, others	Emission limitations, chemical reformulations, and product use restrictions to reduce TACs and nonreactive VOCs with health impacts; labeling program	Limited (some indirect)
Household & Office Equipment and Appliances (computers, photocopy machines, vacuum cleaners)	Particles, styrene, some other VOCs, phthalates, ozone, PBDE	Emission limitations, local exhaust requirements	No
Pesticides (insecticides, herbicides etc, used indoors and outdoors; track-in, drift.)	Chlorpyrifos, diazinon, permethrin, DDT, dieldrin	Formulation and application changes for indoor use	Limited

1. Individual sources may be higher or lower than the source category ranking.
2. All of the examples of pollutant sources may not emit all of the pollutants listed in the corresponding box in column two.
3. Air pollutants may be identified as Toxic Air Contaminants (TACs) by the California Air Resources Board, and/or identified as Proposition 65 chemicals; or, criteria (traditional) air pollutants.
4. Public education, economic incentives, and non-regulatory approaches should also be used where appropriate. The actual approach taken would be determined after extensive discussions with the relevant industries, in consideration of costs, feasibility, and effectiveness..

- **Household appliances and office equipment** such as computers, copy machines, and vacuum cleaners can emit a variety of pollutants such as particles, ozone, various VOCs of concern, and PBDEs. In most cases, these pollutants are emitted directly into the living or working area, and thus are of concern. Additionally, more and more office equipment is being purchased for use in the home, increasing the number of people potentially exposed. Emissions from each type of appliance could be addressed through emission limitations and/or requirements for local exhaust of the emissions. Because emissions information on many specific sources in this category is outdated or lacking, mitigation efforts for these products are a medium priority.

- **Pesticides** are used indoors and around the perimeter of buildings to control household pests such as ants, spiders, and cockroaches. Pesticides residues may be more persistent indoors than outdoors due to the lack of natural degradation forces such as ultraviolet light, high temperatures, wind, and rain. Pesticides can be tracked in from outdoor application and drift into the home after outdoor spray application. In rural areas indoor concentrations may be greater due to increased use of pesticides for agricultural purposes. Levels of pesticides have been measured in both air samples and house dust samples. Continued research and intervention by the U.S. EPA and DPR are needed to assure the least toxic pesticides are registered for indoor use and the formulations prohibit excessive human exposure. Most importantly, the implementation of integrated pest management approaches should be expanded to reduce the need for pesticide application. The U.S. EPA banned the use of chlorpyrifos and diazinon in indoor environments in 2000 and 2001, respectively. The California Department of Pesticide Registration (DPR) also governs the use of pesticides.

VIII. OPTIONS TO MITIGATE INDOOR AIR POLLUTION

This report has shown that there are many sources of indoor air pollution that produce substantial adverse health effects, result in lost productivity, and require considerable expenditures for health care. Despite these facts, there is no systematic program to improve indoor air quality, there are relatively few regulations or standards to specifically address indoor air quality problems, and few resources focused on effectively addressing problems and promoting improvements. Current efforts to address indoor pollution are not commensurate with the scope of the risk to health it poses to Californians.

General Mitigation Options

Ambient (outdoor) air quality is protected through a comprehensive system. In California and under federal law, ambient air quality standards are established for traditional (criteria) pollutants and must be attained. Under other state authority, pollutants identified as toxic air contaminants must be reduced to the maximum extent feasible. The approach used to reduce toxic air contaminants in ambient air, in which source emissions are reduced without setting enforceable air quality levels, seems most applicable to indoor air, together with increased attention to proper building operation and maintenance. Action to reduce indoor emissions and exposures would assure reduction of exposure and risk from key sources, and should be a major component of a new effort to address indoor air. Other approaches including public education, product testing and labeling, improved building codes, and setting of maximum exposure guideline levels, should also be part of the mitigation program. The following elements of an indoor air pollution reduction program are recommended for consideration:

1. **Create a management system for indoor air quality** that establishes a comprehensive program for assessing indoor health problems, identifying the actions needed to reduce the most significant problems, and setting guidelines, emission limits, or other requirements that will be effective in reducing the health impacts of indoor sources. As discussed in Sections 4 and 6 of this report, many agencies' actions affect indoor air quality, and a few have limited authority over some aspect of indoor air quality, but no state (or federal) agency has the authority or mandate to conduct a comprehensive indoor air pollution mitigation program. Such a program is needed, and should be fully coordinated with activities of other agencies whose actions affect indoor air.

2. **Establish emission limits,** when needed, for indoor pollutant sources that pose excessive risks due to their indoor emissions. These might include air cleaners, building materials, furnishings, combustion appliances, and others. While ventilation authority exists in the Energy Commission and Cal/OSHA, no state agency has a direct mandate to establish emission limits for indoor sources for the purpose of reducing indoor exposure and risk. Establishment of such limits would better protect public health, and may reduce (but not eliminate) the amount of ventilation needed under certain circumstances in some buildings, thus saving energy. Compliance could be accomplished by requiring emissions testing through an independent laboratory certified by the state, and submittal of the data to the lead agency.

3. **Require manufacturers to submit building materials, furnishings, combustion appliances, consumer products, and other significant sources for emissions testing** by an independent laboratory certified by the state, and to report those results to the state and to the public. Also, require results to be transmitted to the public via product labeling or accompanying materials in language consumers can understand. Implementation of a required test program could prove to be an effective approach, at least for reducing indoor pollutant levels in new buildings. A prototype emissions testing program has already been developed for reducing toxic VOCs from building materials and furnishings, and is designed to protect human health state sustainable building projects (Section 01350, State of California, 2002). A partial list of products that meet this specification is available at http://ciwmb.ca.gov/GreenBuilding/Specs/EastEnd/. However, there is currently no requirement for state agencies or others to use these guideline emission specifications, and only limited incentive for them to do so. Other national and international emissions test protocols that are widely used also are available.

4. **Make children's health in schools, homes, and care institutions the top priority**. Implement the recommendations for schools in Section 7.2 of this report. In schools and public daycare centers, require the use of building materials that are certified to be low-emitting, and require that school HVAC sytems be quiet (under 45 decibels) and well maintained. Increase efforts to reduce children's exposure to environmental tobacco smoke. Increased education and outreach efforts to smoking parents and caretakers are needed to inform them of the health dangers of second-hand smoke, and the actions they should be taking to protect children under their care from these dangers.

5. **Develop indoor air quality guidelines** for homes, schools, offices, and institutional living quarters. These would largely identify "Best Practices" for the design, construction, operation and maintenance of public, commercial, school, and institutional buildings. In some cases, they might include the identification of healthful levels or "bright lines" for some pollutants to be used as goals for mitigation activities and "best practices", but would not have an associated compliance program. They should also include performance measures for buildings and appliances, and valid certification requirements for professionals directly involved in indoor air quality-related occupations. Full commissioning should be required for all new public, commercial, and institutional residential buildings, to assure that they are constructed and operate as intended, and that they provide acceptable indoor air quality. ASHRAE Guidelines (1993, 1996) provide basic guidance for building commissioning, but state requirements are needed.

6. **Amend building codes to address indoor air quality, with a focus on assuring adequate ventilation under all circumstances**. For example, unvented cook stoves, ovens, and combustion appliances should not be allowed in residences. They should be

vented to the outdoors, such as through direct venting or an automatic (but quiet) exhaust fan that is activated when the appliance is turned on. Similarly, building codes should be established and enforced to prevent mold problems, residential ventilation issues, and others.

7. **Fund an outreach and education program focused on professionals,** including health professionals, teachers, school facility managers, and others who must be able to identify and remedy indoor air quality problems. Such individuals have many obligations, yet play a key role through their occupation in initial identification, prevention, and mitigation of indoor air quality problems. Most need more in-depth information and training on indoor air quality than they typically have had. Training and technical assistance should be provided for the private sector to develop the skills and services needed for high-quality building commissioning, operation, and mainenance.

8. **Conduct more research on indoor air quality**. Several high priority areas are specifically identified in this report for further research. Because of the known serious health impacts of ambient PM and recent studies showing high emissions of PM from indoor sources, research on the health effects of indoor PM are a high priority. The health effects of terpene-ozone reaction products and the extent of people's exposures to them, as well as other indoor chemical reaction products, also are key areas warranting focused research. There are many new chemicals introduced into the product mix each year, yet few have had full health and exposure studies completed. The effects of more recently identified indoor chemicals, such as PBDEs, warrant further investigation. Improved methods and protocols to detect indoor dampness and hidden mold growth are also needed. Synergistic and cumulative health effects are suspected for a number of indoor pollutants with similar structures or properties, yet little research has been conducted in this area. Finally, mitigation approaches assumed to be effective have sometimes been found to be much less effective than anticipated; the effectiveness of recommended or required mitigation measures should be confirmed through appropriately designed studies to assure that the necessary reductions in exposure and risk will be achieved.

9. **Fund an Innovative Clean Air Technology program (ICAT) for indoor air quality** to foster the development and commercialization of legitimate, cost effective technologies that can improve IAQ. For example, improved low-noise ventilation technologies, improved air monitors and assessment tools, and effective low-noise air cleaners are needed. ARB's current ICAT program, focused on improving outdoor air quality through improved technology, has been very successful in bringing new technologies to commercialization in California, adding new options for reducing air pollution while also bringing jobs and investment into the state. An indoor air quality ICAT program would be expected to do the same.

All of these suggested mitigation options are feasible if appropriate mandates and resources are provided. The feasibility of individual measures, such as emission limits for a specific type of product, cannot be determined without substantial additional information. As discussed in this report, alternative products or formulations are already available for some of the indoor sources of current concern. However, prior to taking any regulatory action, a more detailed assessment of the specific remedies available, including technological and economic feasibility, would be needed. Additionally, like ARB's current regulatory programs, any emission limitations or other mitigation measures should be developed with continuous discussion and review by stakeholders, the public, and other state agencies.

Mitigating Indoor Pollution in Schools: An Urgent Need

The Air Resources Board and Department of Health Services recently completed a statewide study of kindergarten through 12th grade public schools entitled "Environmental Health Conditions in California's Portable Classrooms" (ARB/DHS, 2003). Results showed there are a number of serious, widespread environmental health problems in California schools that need to be addressed. These problems were found in both portable (relocatable) and traditional (site-built) classrooms. Government standards and guidelines that are designed to protect children in classrooms and other buildings are essentially lacking; thus, results were compared to the most relevant environmental health guidelines and standards available, primarily from professional societies and government agencies.

Problems in Schools

The primary problems found include:

- Inadequate ventilation with outdoor air during 40 percent of class hours, and seriously deficient ventilation 10 percent of the time. This is often due to teachers turning off HVAC systems because of excessive noise.

- Formaldehyde air concentrations exceeded guideline levels for preventing acute eye, nose, and throat irritation in about 4 percent of the classrooms; nearly all classrooms exceeded guidelines for preventing long-term health effects, including cancer.

- Obvious mold in about 3 percent of classrooms, and water stains and other potential mold indicators in about one-third of classrooms, due to inadequate maintenance.

- Noise levels in all classrooms exceeded 35 decibels, a voluntary standard for classrooms; one-half of the classrooms also exceeded 55 decibels, the level used for outdoor nuisance regulations. Excess noise was primarily attributable to noisy ventilation systems.

Recommendations to Address the Problems Identified

Recommendations to address the problems identified in the study were developed in consultation with state agencies, industries, school officials, and other interested stakeholders. Actions are needed at all levels. A total of 16 recommendations are discussed in the November, 2003 Report to the Legislature. These are presented in two groups in the report: Group 1 includes high priority, high benefit actions that can be achieved at relatively low cost and should be accomplished in the near term, while Group 2 recommendations will require a longer timeframe and/or more substantial resources to accomplish. The recommendations fall into four general approaches needed to remedy and prevent the problems seen. These include:

- Direct and assist schools to comply with state regulations, especially Cal/OSHA's workplace regulations related to ventilation, moisture intrusion, and other aspects of building operation and maintenance. Schools should conduct a self-assessment and implement an indoor air quality management program, like that in U.S. EPA's *IAQ Tools for Schools Program.*

- Develop and promote "Best Practices" for design, construction, operation, and maintenance of school facilities. The CHPS manuals provide comprehensive guidance at no charge.

- Improve support (both funding and training) for school facilities and staff. Stable, long-term funding mechanisms are needed to assure adequate and timely operation and maintenance.

Postponed maintenance often results in greater costs. Focused training programs for administrators, facility managers, and teachers are needed: those closest to the classroom are often not aware of current "best practices" for operation and maintenance of classrooms.

- Establish guidelines and standards for school environmental health that are protective of children. Noise, lighting, and chemical contaminant levels appropriate for school children need to be identified.

Some actions have already been taken to begin to address these problems; however, they constitute only a first step toward realizing actual improvements in school conditions. Only a small percentage of schools and districts have actively pursued the many tools that are readily available to them to improve the school environment. The CHPS' *Best Practices Manuals*, U.S. EPA's *IAQ Tools for Schools Kits*, and the LAUSD's "Safe School Inspection Guidebook" are all available on the Internet free of charge, yet the number of California schools utilizing these tools is small. A proactive effort to implement the recommendations of the report is needed.

The complete *Report to the Legislature on Environmental Health Conditions in California's Portable Classrooms* is available at http://www.arb.ca.gov/research/indoor/pcs/pcs.htm.

IX. SUMMARY

Indoor pollution causes substantial, avoidable illness and health impacts – ranging from irritant effects to asthma, cancer, and premature death – and costs Californians billions of dollars each year. Because there are numerous sources of pollutants in indoor environments, and because people spend most of their time indoors, exposure and the associated risk is substantial. Many agencies, professional groups, and organizations have taken actions to reduce indoor pollution, but these have been piecemeal and are not sufficiently effective in addressing the problem.

There are many actions that could be taken to significantly reduce indoor emissions and exposure. If experience in controlling sources of outdoor pollution is repeated relative to indoor sources, many of these measures will be low cost and will provide substantial health benefits. A focused risk reduction program is needed to effectively assure acceptable indoor air quality in California homes, schools, and public buildings. A program that stresses direct emission reductions and includes improved building codes and ventilation, increased public and professional education, product labeling, and advisory standards is recommended. Indoor air cleaning devices (especially ozone generators), biological contaminants, building materials and furnishings, combustion appliances including woodstoves and fireplaces, ETS, and radon are high priority source categories for mitigation. Architectural coatings, consumer products, household and office equipment, and pesticides are also of concern, but are a lower priority than the other categories identified. Special priority should be paid to measures that reduce children's exposures.

It should be noted that indoor air controls cannot be substituted for the state and national ambient air quality programs. As discussed above, indoor and outdoor pollution operate in tandem, increasing the health risk to all Californians. That means that any new initiatives to mitigate indoor air pollution must be accomplished alongside California's decades-long efforts to improve our outdoor environment.